SCALING RECYCLED PLASTICS ACROSS INDUSTRIES

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RESEARCHED BY JOS Vlugter, MSC CANDIDATE, STRATEGIC PRODUCT DESIGN, DELFT UNIVERSITY OF TECHNOLOGY
ELLEN MACARTHUR FOUNDATION

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Co.Projects are opportunities for formal collaboration between CE100 members. They are driven by members, for members and their focus can range from research initiatives to pilots to toolkits. Co.Projects leverage the CE100 network with the aim of exploring opportunities and overcoming challenges which are commonly and collectively faced by organisations making the transition to a circular economy, and which organisations may not be able to address in isolation.

SCALING RECYCLED PLASTICS ACROSS INDUSTRIES

This collaborative project aims to map material pathways and loops of engineering plastic (HIPS, PC/ABS, ABS, PP) used in products and focus on closing the loop in these materials. The team has delivered a paper on plastic streams, including evaluations of closed loops, and recommendations for closing loops, focusing on electronic and electrical equipment and cars. We also set up a network of manufacturers, users, and recyclers of plastic from CE100 membership to discuss possible pilots for select closed loops.
CE100 CO.PROJECT MEMBERS

Project Lead

Contact: Markus Stutz, Director EMEA Product Compliance Engineering & Environmental Affairs
Email: Markus.Stutz@dell.com

Project Participants

Contact: Sylvie Thomas, Head of Corporate Social Responsibility
Email: sylvie.thomas@lexmark.com

Contact: Eelco Smit, Sustainability Director, Consumer Lifestyle
Email: eelco.smit@philips.com

Contact: Christophe Garnier, Project Manager
Email: christophe.garnier@renault.com

Contact: Florence Delange, Advanced Materials and Processes Director
Email: florence2.delange@schneider-electric.com

Contact: Sabine Zariatti, Partnerships Development Manager,
Email: sabine.zariatti@suez.com

Contact: Jean Marie Thierry, VP Dismantling & Circular Economy
Email: jean-marie.thierry@veolia.com

Researcher And Report Author

Contact: Jos Vlugter, MSc Candidate, Strategic Product Design
Email: josvlugter@gmail.com
CONTENTS

EXECUTIVE SUMMARY

INTRODUCTION

I. PLASTICS RECYCLING

II. CASE STUDIES:
   • DELL: CLOSED LOOP ABS RECYCLING
   • RENAULT: CLOSED LOOP PP RECYCLING
   • LEXMARK: CLOSED LOOP CARTRIDGE RECYCLING

III. BOTTLENECKS IN SCALING UP CLOSED LOOP RECYCLED PLASTICS
   • COLLECTION OF WASTE PLASTICS
   • PROCESSING OF RECYCLED PLASTICS
   • MANUFACTURING WITH RECYCLED PLASTICS

IV. RECOMMENDATIONS
   • BRAND OWNERS
   • VALUE CHAIN PARTNERS
   • INDUSTRIAL SECTOR AS A WHOLE
   • POLICY MAKERS

V. CONCLUSION

VI. GLOSSARY

VII. REFERENCES
EXECUTIVE SUMMARY

The members of this collaborative project came together to create an overview and a deeper understanding of the challenges involved in creating closed loops for engineering plastics sourced from electronics and cars. Together they aimed to develop recommendations for addressing these challenges.

In developing the project’s scope, the members provided and assessed case studies, conducted interviews with industry experts and complemented these findings with literature research that investigated state-of-the-art of plastics recycling.

The analysis resulted in a map and a description of the most important bottlenecks to closed loop plastics throughout the value chain. It also led to two detailed case studies of closed loop plastics schemes that have already been implemented as well as leading to further recommendations for improvement.

Key findings

• Closed loop recycling of plastics is hindered by the scale and effectiveness of collection activities, the lack of a market for recyclates and the limited skills, knowledge, scale and collaboration of and between value chain partners.

• Brand owners can improve the diffusion of recycled plastics in their products by embracing the aesthetic limitations of recyclates, re-evaluating critical material requirements and developing step-by-step processes for scaling the application of recycled plastics in their organisations.

• Establishing a closed plastics loop requires a value chain partner (often the brand owner) to take on the role of coordinator, safeguarding the quality of the process along the entire value chain while developing the skills and aligning the interests of all parties involved.

Following the publication of this co.project report, the companies will continue to work together to generate knowledge and look for opportunities for collaboration on an individual basis, possibly in form of a pilot project.

“We need to continue taking one step after the other”

“One insight gained by leading this project was the fact that closed loop recycling of plastics is already happening in many different companies and industries. Every company member had its success story to share, some of which are included in this report. Most of these success stories however are not known and we need to make a better job of highlighting the accomplishments so far.

Another insight that we gathered quite early in the process was that closing the loop across industries was not really feasible. Every industry seems to have their set of preferred/used plastic (PC, ABC, PC/ABS for the IT industry, PP for automotive, etc.). Hence closing the loop can realistically only happen within these industries, amplifying certain bottlenecks that were identified. One suggestion that we came up with in discussions was to focus on certain streams
in certain regions/countries to move ahead with closing the loop. For instance piloting closed loop recycling plastic used in ICT in China (large user/large manufacturer) or PP in cars in Europe could be promising first steps. It was also very interesting to understand that all members of the project faced very similar operational and strategic bottlenecks. All reported issues around collecting the used plastics, processing the collected plastics and manufacturing new plastic parts using recyclate. The report details these bottlenecks very nicely. The hope was of course to offer some solutions to these bottlenecks. However there is much more that needs to be done before scaling close loop recycling plastic can happen and we are looking forward to see what the team working on the NPEC comes up with. In essence, closing the loop is a long journey. We have made our first successful steps and need to continue taking one step after the other.”

Markus Stutz
Director EMEA Product Compliance Engineering & Environmental Affairs, Dell

* See Glossary for plastics

INTRODUCTION

This report is the result of a CE100 collaborative project with the following objectives:

- Evaluating existing closed loops of post-consumer plastics, and providing recommendations to overcome barriers to closing these loops, based on literature review and expert interviews
- Using best practice examples to identify opportunities for scaling the closed loop use of plastics
- Mapping the demand for recycled plastics among the participating companies in order to find potential for collaborative closed loop pilot projects, with a focus on polypropylene (PP), polycarbonate/acylonitril butadiene styrene (PC/ABS), acrylonitril butadiene styrene (ABS) and high impact polystyrene (HIPS).
I. PLASTICS RECYCLING

Few materials have so profoundly transformed the way we use, design and manufacture the products that define our everyday lives as plastics. The versatility their unique combination of properties provides makes them the material of choice for a great variety of applications. Their durability, high strength-to-weight ratio and relatively low costs compared to alternative materials (Andrady & Neal, 2009), has, over the course of the 20th century, made plastic an integral part of virtually every industry.

As our global demand for plastics increases, so does the amount of plastic waste that is created. Out of the 25.8 million tonnes of European post-consumer waste plastics that were collected through official channels in 2014, 29.7% was recycled. The remaining waste was either incinerated for energy recovery (39.5%) or landfilled (30.8%) (Plastics Europe, 2016). According to these data, 80% of post-consumer plastics waste that was recycled in 2014 came from packaging applications, which reached a recycling rate of 39.5%. Packaging, however, represents only about 40% of the EU28+NO/CH\(^1\) annual plastics demand (Plastics Europe, 2016), illustrating the significant untapped potential of recycling of non-packaging plastic products and components.

In lower and middle income economies plastics recovery rates are generally much lower, since these countries often lack the necessary (formal) collection and/ or recycling infrastructure. Estimations by the United Nations Environment Programme (cited in Gourmelon, 2015) show that high percentages of domestic waste plastics in Africa, Asia and Latin America are not being collected. Instead these plastics, along with other kinds of waste, are either burned in the open or simply discarded, causing health and environmental hazards. To mitigate the negative effects of plastics use, global recycling of post-consumer product plastics needs to be scaled up drastically.

Plastics recycling technologies can be subdivided into mechanical recycling and chemical recycling. Mechanical recycling generally consists of size reduction (i.e. shredding or pulverising) of the plastics waste after which the material is sorted, washed, dried, extruded and compounded (Al-Salem, Lettieri and Baeyens, 2009). Usually, the resulting properties are less well defined than for virgin plastics. In chemical recycling plastic waste is chemically returned to feedstock for new plastics (Al-Salem et al., 2009). The properties are as for virgin plastics, but the required energy input is higher than for mechanically recycled plastics. Chemical recycling is not (yet) commercially viable (Hopewell, 2009).

Of the plastics that are actually recycled, most are downgraded (or ‘down-cycled’) into applications that are of a lower value than their original purpose. Often these products are themselves no longer recyclable. Closed loop recycling, in which the material is brought back to an equal or comparable level of quality, currently represents only a small amount of all plastics recycling activities (Ellen MacArthur Foundation, 2016). Here we will consider ways to scale up the closed loop (re)use of post-consumer plastics.

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1 The European Union, Norway and Switzerland
II. CASE STUDIES

Two best practice cases of closed plastic loops are described to uncover the main barriers, and provide recommendations for successful implementation of closed loop plastics.

**Dell: Closed Loop ABS Recycling**

In 2012 Dell made a commitment to 21 ambitious sustainability goals that it seeks to achieve by the year 2020. The goals of this 2020 Legacy of Good Plan cover the company's entire value chain and are divided into 3 main areas of action: Environment, Communities and People. One of the environment specific goals is to use 50 million pounds of recycled materials by 2020, of which plastics are an important component (Dell, 2016a). In 2015 Dell used 14.1 million pounds (6.4 million kg) of recycled plastics in its products, 3.4 million pounds (1.5 million kg) of which was sourced from its closed loop efforts (Dell, 2016b).

*Figure 1: Dell: Closed Loop ABS Recycling*

**Take-back efforts**

In 2004, Dell initiated a collaboration with the U.S. non-profit organisation, Goodwill, to establish the Dell Reconnect Program, which offers consumers free recycling of
computers, monitors and computer accessories. Used desktops, laptops, keyboards and other related equipment are collected at over 2000 participating Goodwill locations throughout the United States. The program takes back products in any condition, from any electronics brand and all the donations that are made are tax deductible (Dell, 2016c). Over the years more than 464 million pounds of electronics waste were collected and either re-used or recycled (Dell, 2016b). The Reconnect Program also contributes to Goodwill's mission of creating jobs and skills training opportunities for those who experience barriers to employment. At certain participating Goodwill locations devices that have not yet reached their end-of-life are refurbished and resold at affordable prices (Dell, 2016c).

**Recycling process**

End-of-life electronics waste that is collected at Goodwill locations in the state of Texas and a number of neighbouring states is transported to Wistron GreenTech, an electronics recycler located in McKinney (Texas), where the products are manually dismantled. While other materials (such as metals) are extracted and re-sold in the commodities market, plastic components are sorted out and baled, after which they are shipped to China for further processing.

At Wistron Advanced Materials’ facility in Kunshan the bales are broken and the plastic parts are shredded and sorted. The sorted scrap is then granulated into 6-12 mm sized chips that are purified and dried. After going through a formulation and mixing process the material is extruded and pelletised (Resource Recycling, 2013). The post-consumer recycled material is blended with virgin plastics into a mixed resin that contains up to 35% recycled content (Dell, n.d.). This mixed resin is shipped to moulders, where it is used to mould new parts, such as the stands and back plates of monitors and all in one’s.

**Dell Optiplex 3030**

An example is the Dell Optiplex 3030 all-in-one, which was launched in 2014. It is the first product in its industry to obtain UL Environment® closed loop certification, as it has a guaranteed minimum of 10% closed loop recycled content in its chassis enclosure (Dell, 2016c).

Figure 2: Dell Optiplex 3030 all-in-one
Challenges and Success Factors

To create a closed plastics loop Dell has had to navigate several constraints. Firstly, the electronics products that are retrieved through the Reconnect program are often several generations old and recycling their materials in such a way that they can be re-used in new electronics products is challenging.

Secondly, Dell’s current closed loop activities for plastics are focused on ABS, with which it has had the most success in restoring the post consumer material to a level of quality that meets the requirements for new components. Experiments with other plastics, such as PC/ABS, encountered more difficulties. An example is the lack of consistency of the source material, which makes it harder to achieve the desired quality or the right ratio of PC and ABS in the recycled resin.

Thirdly, it has proved difficult to apply the closed loop material without parts showing aesthetic defects such as flow lines. And finally, applications that use PC/ABS are often subjected to specific flame retardant requirements that are not necessary for the types of components that are made with ABS.

Since adding post-consumer recycled content impacts the material’s performance, the mixed ABS resin is confined to applications in which it can be used without compromising the quality of the part, particularly where the product’s aesthetics or durability are concerned. This means that the use of closed loop recycled resin is restricted to relatively large, exterior components for monitors, desktops and all-in-ones, which tend to have a greater wall thickness. These types of parts are the most suitable candidates for the application of recycled resin because their mechanical requirements are less stringent than those for components of other products such as notebooks or tablets. Moreover, the moulding process for thicker parts is more forgiving when it comes to achieving the desired outcome, for instance in terms of mould flow or aesthetic quality.

The Reconnect program creates multiple incentives for consumers to return their old products. Expanding the Reconnect program to accepting used computer equipment from different brands has helped to further secure a stable supply of end-of-life electronics. The inclusion of competitor products is possible because the majority of brands in the consumer electronics industry use a relatively homogenous set of materials for similar types of components.

Dell has a longstanding relationship with Wistron, which expanded after the company first initiated its plastics recycling activities. Because of this Wistron is highly invested in making Dell’s closed loop recycling program work. It is highly integrated along the circular value chain, which is unique for an ODM. In Kunshan, the company has consolidated capabilities for bale breaking, shredding, sorting, purification, modification, colour matching and compounding in a single facility. This cuts back on the amount of different companies Dell needs to work with and ensures effective collaboration and communication between different value chain partners. A Wistron moulder, for instance, is likely more comfortable with being told to only use a certain material provided by a different Wistron company than a third party moulder. By closely collaborating with Wistron GreenTech it is easy to make adjustments to the Reconnect program to better meet Wistron’s needs.

Dell is actively exploring possibilities to expand its closed loop recycling program beyond the Texas area in the U.S. as well as into other regions such as Europe. In case of the latter, it attempted to connect local recyclers with Wistron’s activities in Kunshan, but this has so far been unsuccessful due to financial limitations as either...
the costs of logistics are too high or the price of their scrap is higher than what Wistron is currently willing to pay. Potential local manufacturers of closed loop resins are also considered, yet these often lack the necessary capacity or their resins are not (yet) up to specification.

**Renault: Closed Loop PP Recycling**

The ICARRE95 project is a collaboration between Renault, vehicle dismantling network INDRA, plastics recycler Synova, metals recycler Duesmann and more than 50 additional contributing parties (ICARRE95, n.d.). It was established to increase the recycling rate of end-of-life vehicles by developing feasible technological and economic pathways for the recycling of their materials and by bringing structure to the fragmented and non-transparent collection and valorisation of ELVs in France. The project is focused on automotive materials and parts that are usually not (or inadequately) recycled, such as plastics, foams, textiles. It demonstrates the economic and environmental viability of (closed loop) recycling at scale within the automotive sector.

*Figure 3: Renault: Closed Loop PP Recycling*

The proportion of plastics that are used in vehicles is increasing, mainly due to weight considerations. In 1970 plastic components made up a mere 6% of an average vehicle’s total weight. Projections by A.T. Kearney (2012) show that by 2020, their share will have grown to 18%, primarily at the expense of metals.

In addition to the environmental and economic benefits of applying post-consumer
recycled plastics, stringent EU regulations for the recycling of end-of-life vehicles (ELVs) form a principal driver for Renault to pursue closed loop plastics recycling. European directive 2000/53/CE obligates EU member states to ensure that economic actors that deal with the recycling and collection of end-of-life vehicles reach a recovery rate of 95%, of which the majority (85% of a vehicle's materials by weight) needs to be recycled (ICARRE95, n.d.). For Renault, closing the loop also means ensuring a stable supply of materials by effectively becoming its own plastics supplier.

Collection of used plastics

Retrieving a substantial amount of the value embedded in ELV parts and materials is challenging because the collection of ELVs is widely dispersed and the level of quality of dismantling activities varies greatly. By collaborating closely with INDRA, Renault and its contributors were able to significantly improve the quality and effectiveness of collection and dismantling processes at the organisation's network of 400 vehicle dismantling centres throughout the country. Recovery of spare parts has traditionally been the dismantling centres’ primary source of revenue, which meant that processes for the retrieval of materials remained underdeveloped. These processes were improved by creating more ergonomic work stations, providing practical, illustrated instruction sheets for the dismantling of specific models and by developing a custom mechanical tool to assist in the recovery of materials from large components (Gallone, n.d.).

The adaptations that were made to the dismantling and shredding processes were informed by the input requirements of recycling partner Synova. The company’s expertise in compounding (recycled) plastics for the automotive industry helped to establish clear quality demands (for instance regarding the amount of contaminants) that needed to be met by both dismantlers and shredders. These resulting materials are authorised for use in structural, as well as some visible applications, such as door panels (Gallone, n.d.).

Today, 50 of the 280 kilograms of plastics that are used in a Renault Espace come from a recycled source (Garnier, 2015). Certain parts, such as wheel arch housings, are made entirely with recycled PP, a share of which is obtained from closed loop sources.

Challenges and Success Factors

In order to retrieve sufficient volumes of plastics to make closed loop recycling feasible, several operational and logistical issues needed to be resolved.

One of the biggest challenges was providing the right incentives for dismantlers to properly retrieve plastic parts. For plastics recovery to be worthwhile, dismantlers need to be compensated for the additional effort of extracting these materials. Because of this, fluctuations in material prices can quickly put pressure on the economic viability of ELV plastics recovery.

A related concern is the level of quality of the materials that are retrieved. Renault has taken measures to ensure that dismantlers only recover parts that are suitable for recycling and prevent contamination with other materials as much as possible. A bumper, for instance, may have some elastomer parts or electrical wiring attached to it and cannot be accepted unless these can be removed. Identifying and sorting ELV plastics is further complicated by the fact that manufacturers in the automotive industry have different material specifications for the same types of parts. Renault
might use an unfilled grade of PP in its bumpers, while a competitor might use polyethylene or filled PP grades. Providing clear, illustrated instructions for different vehicle and component types has helped to increase the quality of the batches that are collected and has reduced the amount of contaminates (e.g. other polymers, metal scrap, dust) they contain.

Organising the logistics after the dismantling stage was one of the key challenges. On average about 2 to 4 plastic parts are retrieved per end-of-life vehicle. This means that the output of individual dismantlers is between 2 to 10 kilograms per ELV. In order to make their recycling economically feasible, Renault needs to be able to scale from mere kilograms to several tonnes of material. Renault addressed this problem by establishing a number of collection platforms throughout the country where parts that are retrieved from dismantlers in the area are stored - this can take several months up to a year- until there’s enough material for cost effective collection.

As is the case with dismantling, the quality of shredding and sorting processes can also vary greatly between companies. Generally, sorters are small companies for whom Renault’s recycling activities only make up a relatively minor part of their business. It is therefore difficult to persuade them to invest in more advanced sorting technologies, as these are not required for their primary activities.

An important factor of Renault’s success is the ability to recycle the material while maintaining its mechanical quality. The recycled PP grades that were developed in collaboration with Synova are technically equal to a virgin alternative, yet are not blended with virgin material. While the latter could, in theory, make it easier to apply recycled resin, the additional process steps that it would require (re-compounding a granulate mix of the recycled material with a virgin grade) would in this case not be cost effective.

Another success factor is Renault’s ability to coordinate the development of new skills, materials and processes in collaboration with a large network of value chain partners and making sure their interests are aligned. Working with INDRA, for instance, allowed Renault to adjust and build on an existing network of dismantling facilities, which means that a part of the required infrastructure was already in place. A downside is that expanding the closed loop recycling activities beyond France requires these efforts to be repeated locally.

Lexmark: Closed Loop Cartridge Recycling

In order to close the loop for the toner cartridges used in its printers, Lexmark has established a free collection program (LCCP). In addition, Lexmark offers recycling of its printers through the LECP (Lexmark Equipment Collection Program).

Customers are encouraged to return their empty cartridges by post, either by using the original packaging, which comes with a return label, or in a plastic return bag that can be ordered for free on Lexmark’s website. Through the program, which was first created in 1991 and is currently active in over 60 countries, approximately one third of all cartridges that are sold are retrieved for reuse or recycling (Lexmark, n.d.).

Cartridges that are no longer suitable for reuse are dismantled and their materials (i.e. metals and plastics) are recycled. The plastic material is then cleaned and reground at a Lexmark facility, after which it is re-extruded into new pellets. This resin is tested thoroughly to ensure that it conforms to internal specification. It is then shipped to moulders who use it to manufacture new cartridge parts. Out of the toner cartridges that were returned in 2015, 36% of their material (by weight) was reused. Lexmark
aims to increase this recovery yield to 50% by 2018 (Lexmark, 2015). Over the course of 2016, the company used approximately 1.6 million pounds of internally sourced closed loop material, ensuring that its cartridges contain on average 18% recycled plastic content. By retaining control over the reuse and recycling of its own cartridges Lexmark has created a closed loop system in which it can reliably control the quality of both the input and output of this manufacturing process (Drummond, 2015).

### III. BOTTLENECKS IN SCALING UP CLOSED LOOP RECYCLED PLASTICS

A product's recycling process can be broken down into three main steps (Tanskanen, 2013):

- Collection of waste materials.
- Sorting and reprocessing waste into raw materials.
- Using recycled material to manufacture new products.

Based on insights that were gathered from the literature, the two case studies and interviews with industry experts, the most important bottlenecks in each step of the closed loop plastics recycling process were identified. An overview of these bottlenecks is shown in figure 4.

*Figure 4: Bottlenecks to Closing the Loop for Plastics.*
Collection of Waste Plastics

Collection is Widely Dispersed and Small in Scale

The most costly aspect - in both financial and environmental terms - of recovering a product’s materials is often its return journey from the consumer to a recycling facility (Rahimifard, Coates, Staikos, Edwards and Abu-Bakar, 2009). Since the collection of end-of-life products is widely dispersed and small in scale, sourcing sufficient and stable volumes of waste plastics to make closed loop recycling practically and economically feasible is challenging. (Trucost, 2016).

Without a prearranged take-back scheme in place, it is also difficult to anticipate when a particular product may be returned for recycling. A Lexmark printer, for example, could be retrieved after only 2 years, yet this could also take 10 or even 20 years. As a result it is hard to accurately predict when and which materials will become available again. A related barrier is caused by differences in material specifications between manufacturers, which make the collection of specific parts for closed loop recycling more difficult.

Limited Global Recycling Infrastructure

The scope and level of development of waste collection and recycling infrastructure varies greatly between different regions and countries. While the majority of global plastics waste is generated in European and North American countries, manufacturing of plastic parts (and with it the demand for recycled plastics) has, over the last few decades, shifted to Asia. The domestic recycling infrastructure in these countries, however, remains underdeveloped. This makes it difficult for companies to determine where their focus for future investments into plastics recycling should be.

Complex Shipping Regulations

Complex regulations concerning international shipping of waste also pose a number of challenges to the reverse logistics of end-of-life plastics. Acquiring the necessary paperwork can cause delays that can jeopardise production timelines. There are also financial risks, since each international waste shipment requires a bank guarantee to ensure that the costs of waste treatment at its destination can be met.

Processing of Recycled Plastics

Underdeveloped Market for Recycled Plastics

Although it is developing rapidly, the market for recycled plastics is still small. This is in part due to a lack of demand for recycled plastics, which in turn inhibits investments in material recovery activities. Other inhibiting factors are resistance to change amongst manufacturers (Trucost, 2016) and a lack of knowledge of the additional benefits of (closed loop) recycled plastics, such as securing a stable supply of (lower cost) material.

The economic feasibility of using recycled plastics depends on their cost advantage over virgin alternatives. While most interviewees report being able to achieve lower
input costs by applying post-consumer recycled (PCR) resins (irrespective of low oil prices), some find that low oil prices can decrease their cost effectiveness to the extent that it hinders further diffusion of recycled plastic content in their products.

**Value Chain Partners are Small and not Global**

Unlike suppliers of virgin plastics, recycled plastics suppliers and other value chain partners such as recyclers and sorters are often small, predominantly regionally operating companies (Froelich et al., 2007). The industry’s lack of maturity and global capacity poses challenges with respect to quality, quantity and procurement for companies that want to apply recycled plastic content at scale in their products:

**Value Chain Partners are not Connected**

The different collection, sorting and processing facilities do not cooperate enough and there is insufficient communication between them. Working with recycled plastics already requires careful managing of sourcing and manufacturing. Closing the loop adds further complexity. Brand owners need to safeguard the quality of the process along the value chain while developing the skills of an entire economic sector and making sure the interests of all value chain partners are aligned (CE100, 2016).

**Technological Limitations of Sorting and Reprocessing**

Closed loop recycling requires effective separation of polymers from waste streams while preventing contamination and losses in mechanical and aesthetic quality during reprocessing and reuse (Hopewell et al., 2009). Common obstacles to reprocessing are cross-contamination, separation from non-polymer materials, multi-layer films that are difficult to separate or characteristics that make a material undesirable to use (for instance if it is too wet) (SPI, 2015).

**Lack of Knowledge and Skills**

Value chain partners often lack much needed skills and knowledge regarding polymers. Manual sorting, for instance, requires trained staff and - particularly at smaller companies - a lack of training often results in unnecessary contaminations. A batch of PP parts, for example, can easily be contaminated with PU foams at the dismantling stage.

**Restrictions on Contaminates**

Another challenge is controlling for contaminants in the waste stream. While regulations limiting the use of additives such as flame retardants have become more stringent over the years, older products in which halogens - such as bromine - were widely used are still being retrieved for recycling. Removing these contaminates during the recycling process is challenging and costly (Drummond, 2015).
Manufacturing with Recycled Plastics

Design and Manufacturing Issues

For designers it can be difficult to determine which guidelines for the recycling of plastic components need to be prioritised, as this heavily depends on the way the product is recovered at its end-of-life. Continuous advances in material recovery technologies mean that the product’s end-of-life scenario is subject to change, and that what is considered good design practice today may not be the case in the future (Masanet, Auer, Barillot and Baynes, 2002). Furthermore, design for disassembly guidelines often conflict with other, more critical product requirements. Companies may even be resistant to optimising their designs for end-of-life value recovery if they feel that other stakeholders are the ones that ultimately enjoy the economic benefits (Rahimifard et al., 2009). Several interviewees, however, argued that it is the responsibility of brand owners to help develop a market for end-of-life plastics by designing products in such a way that their embedded value is easily retrieved.

During the manufacturing process, the characteristics of recycled plastics can cause several problems. If a material, for instance, has a strong odour caused by contact with organic waste it can be a reason for moulders to reject it. Moulders may also not be aware that, unlike virgin alternatives, certain recycled grades of materials such as ABS or HIPS require additional drying before they can be moulded. If this does not happen it can result in defective parts. Wider ranges in viscosity between batches can cause more scrap to be generated during moulding, and necessitate more trial runs and adjustments of the moulding process (e.g. temperature, flow rate), which can slow down production.

Mechanical Limitations

Mechanical recycling of thermoplastics generally decreases the material’s mechanical properties, such as its stiffness, tensile strength, ductility and impact toughness (La Mantia, 2002). Because of this they are usually mixed with virgin material. Applying recycled content often requires certain design trade offs (e.g. increasing a part’s wall thickness, adding fillers or metal inserts). Mechanical properties of recycled plastics also show more variation than those of virgin, which means they are often not suitable for use in critical parts (Drummond 2015).

Aesthetic Limitations

Recycled plastics also tend to have a lower aesthetic quality than virgin alternatives, which can make it difficult to expand the use of recycled plastics to parts that are visible to the consumer. Common issues while working with recycled plastics are splay, flow lines and a lower scratch resistance.

Colour is another important concern, as recycled plastics are generally only available in a limited number of colours. Since feedstreams are likely to contain a mix of coloured scraps, it is particularly difficult to create recycled resins in lighter colours such as whites or light greys. Batch to batch variations in colour, or colour variations between different sources can cause inconsistencies in the final product. It can also be challenging to achieve a high gloss on the finished product, which can limit the use of recycled material to applications with a matte finish. Another issue is that
resins are likely to contain slight traces of metallic particles that can cause small imperfections on the surface of a part, which can make it difficult to paint.

Working with recycled resins can result in unique, yet minor aesthetic defects that can be unfamiliar to moulders. While these defects are not necessarily critical, they are often not accounted for in the appearance specifications of the part in question, which can cause moulders to needlessly discard parts that would otherwise be considered acceptable (Drummond, 2015). Manufacturers need to be made aware by identifying and including these common (yet permissible) aesthetic defects in the appearance specifications of parts in which they are likely to cause issues. Being able to accommodate a significant amount of recycled material may also require a change in attitude towards such defects, especially when dealing with parts that are visible to the consumer. This means allowing certain minor imperfections that would immediately be rejected while working with a virgin alternative, simply because of quality expectations.

Lack of Standardisation of Recycled Grades

Recycled plastics lack standardisation; so working with them requires repeated and thorough testing. Using material from different sources can result in consistency issues.

Limited Volumes and Types of Recycled Grades

The volumes and different types of grades of recycled plastics that are currently available on the market are limited, which results in a relatively high supply risk (Drummond, 2015). Because of this it is often necessary to develop custom grades, as was the case for Renault and its partners, who created several closed loop materials that were specifically tailored to the requirements of automotive applications.

IV. RECOMMENDATIONS

An overview of all recommendations is shown in figure 7.

Brand Owners

The aesthetic qualities of recycled resins are usually only considered as limitations, inhibiting the application of recycled content in parts that are visible to the consumer. Yet incorporating significant amounts of recycled materials into a product may require a change in perspective. Philips’ PerfectCare Eco Aqua steam generator is a great example of how companies can embrace aesthetic constraints through innovative product design. It was designed to accommodate recycled content in its exterior components by using dark colours and a matte finish while exploiting changing design trends. The dark colours, contrasted with a bright green colour, may look atypical for its product category but nonetheless result in a highly appealing product
In some cases material requirements for certain applications can be unnecessarily high. This can apply to both mechanical and aesthetic specifications and can make it difficult to substitute virgin plastics with a recycled grade. Designers and engineers therefore need to consider if the minimal material requirements that apply to a certain part are truly critical. If this is not the case then these requirements may be adjusted in such a way that it becomes feasible to apply a recycled resin.

*Figure 5: Philips PerfectCare Eco Aqua*

Companies can improve the application of recycled plastics by developing a step-by-step process that is aimed at maximising the use of recycled contents within their organisation (Gort & Gerrits, 2015). Figure 6 shows an example of such a process by Philips. An important first step is identifying the products and specific parts that contain large volumes of common polymers to focus on.

*Figure 6: Philips’ step-by-step process for the introduction of recycled plastics (adapted from Gort & Gerrits, 2016).*

Another way in which brand owners can help drive demand and thus develop a market for recyclates is by establishing and communicating company targets for the use of recycled resins.

Closing the loop for plastics requires brand owners to take on a new role as coordinator of a complex value chain. To create its closed loop for polypropylene, Renault has established - and cooperated with - a vast network of collaborators throughout France, developing new skills, materials and processes with different value chain partners while ensuring the quality of results throughout each step of the recycling and manufacturing process (CE100, 2016).
There are several things brand owners can do to improve the collection of end-of-life products. Truly effective product take-back schemes are as effortless as possible for the consumer, such as Lexmark’s free toner cartridge pick-up program (Lexmark, n.d.), or provide incentives that go beyond financial compensation. A good example of the latter is Dell’s Reconnect program.

**Value Chain Partners**

Close collaboration between value chain partners, which is critical to the success of any closed loop, requires coordination by one of the stakeholders. While the brand owner seems to be the obvious candidate, as was the case for Renault, a third party service provider could also take on this role. Alternatively, consolidating multiple process steps also has many advantages. A good example is Dell’s recycling partner Wistron, whose subsidiaries cover the entire value chain from waste sorting back to moulding new parts. In addition to cost advantages there is more streamlined communication and collaboration between the different businesses. Froelich et al. (2012) argue that as the plastics recycling industry matures, producers of virgin plastics, plastic transformers and large waste collection companies will each start to expand into recycling activities by incorporating multiple process steps.

**Industrial sector as a whole**

Industries need to cooperate to improve product recovery, for instance by collaborating in industry-wide recycling initiatives. In the Netherlands, for instance, the consumer electronics industry is united in Wecycle, a non-profit organisation that works to improve the collection and recycling of electric appliances.

Another area in which the industry as a whole needs to play a role is the standardisation of recycled grades, which will make it easier to apply recycled resins. Ultimately the effort of buying recycled plastics should be as simple as using virgin. Design guidelines need to be created, while taking into account the most likely end of life scenario for products of specific industries. A good example are the guidelines for designing with recyclates developed by Partners for Innovation (Gort & Gerrits, 2015). For designers it is important to understand which design guidelines need to be prioritised. Industry also needs to improve the compatibility of supply and demand, for instance through online matchmaking platforms.

**Policy Makers**

(Local) governments can use policies to stimulate the development of (closed loop) plastics recycling, such as bans or restrictions on landfills or incineration and lowering taxes for recycled materials compared with virgin materials. Governments also have the power to drive demand through public procurement, or by direct investments in plastics recycling facilities and technologies.
IV. CONCLUSION

Creating closed loop recycling programs for plastics has many environmental and economic benefits. Scaling up their implementation, however, is inhibited by a number of operational and strategic bottlenecks. These bottlenecks occur in each of the three main steps in the process; collection of used plastics, processing the collected plastics and manufacturing with recycled plastics. First of all, cost effective collection of sufficient volumes of EoL materials for recycling is hindered by the widely dispersed and small scale nature of collection networks and the limited development of global recycling infrastructure. Second, reprocessing is subject to a number of challenges ranging from technological limitations to the underdeveloped market for recyclates. Finally, the mechanical and aesthetic properties of recycled plastics should be taken into account in the manufacturing process and in its results, which can limit the possibilities for their application.

One of the objectives of the project was to investigate whether cross industry collaboration on closed loop plastics recycling could result in interesting opportunities for joint pilot projects. By comparing data on the demand for recyclates of each of the participating companies it became clear that there was
limited overlap (both geographically and regarding the material grades that are used) between their activities. Collaboration within industries may prove more fruitful.

Establishing a closed plastics loop requires a significant organisational effort. Brand owners need to take on a new role, safeguarding the quality of the process along the entire value chain while developing the skills of an entire economic sector and making sure that the interests of all value chain partners are aligned. The two cases of closed loop recycling schemes that have been used as examples (closed loop PP at Renault and ABS at Dell) demonstrate the potential of scaling these programs by expanding into other regions, materials and products.

GLOSSARY

ODM: Original Design Manufacturer
ICT: Information and Communications Technology
PCR: Post Consumer Recycled
EPEAT: Electronic Product Environmental Assessment Tool
CSR: Corporate Social Responsibility
MSW: Municipal Solid Waste
ABS: Acrylonitrile Butadiene Styrene
PP: Polypropylene
PC/ABS: Polycarbonate/ Acrylonitrile Butadiene Styrene
HIPS: High Impact Polystyrene
EMF: Ellen MacArthur Foundation
EoL: End of Life

REFERENCES


**La Mantia, F.** (2002). Handbook of plastics recycling. iSmithers Rapra Publishing.


